

NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

Project # SPR 26962Z		Report Period Year 2021 <input type="checkbox"/> Q1 (Jan-Mar) <input type="checkbox"/> Q2 (Apr-Jun) <input checked="" type="checkbox"/> Q3 (Jul-Sep) <input type="checkbox"/> Q4 (Oct-Dec)
Project Title: Use of Smart Rocks to Improve Rock Slope Design		
Project Investigator: Jean Benoit, PhD Phone: E-mail: jean.benoit@unh.edu		
Project Start Date: April 17, 2019	Project End Date: March 31, 2022, extended	Project schedule status: <input checked="" type="checkbox"/> On schedule <input type="checkbox"/> Ahead of schedule <input type="checkbox"/> Behind schedule

Brief Project Description:

Rock slopes pose a hazard to the traveling public when weathering processes dislodge portions of the slope which then fall into the road. Current ditch design practice relies on design criteria developed decades ago in different environments with different rock types. Current hazard rating practice rates the rock slopes based on semi-quantitative measures using the Rockfall Hazard Rating System (RHRS). Both the design of new rock slopes and the hazard assessment of existing rock slopes need improvement to increase safety against rockfall, construct better engineered slopes and reduce short and long-term maintenance costs.

Preliminary work performed at UNH in collaboration with the NHDOT has shown that using a smart rock sensor equipped with a 3-axis accelerometer and 3-axis gyroscope, embedded in a natural rock can provide the necessary field response data to calibrate and revise existing rockfall simulation software models. To achieve this primary goal of improving rock slope design, several objectives need to be considered during this project:

1. Improve the current smart rock (SR) sensor to include altimeter capability. The use of wi-fi technology will also be investigated as a mean to acquire data without sensor removal from the test rocks.
2. Conduct multiple experiments with the smart rock at 10 rock cuts rated A or B according to the New Hampshire RHRS.
3. Analyze smart rock accelerometer and gyroscope data coupled with video recording of each experiment to extract information and parameters as input to current rockfall software packages.
4. Develop a design evaluation protocol for new and existing slopes using smart rock technology.

Scope of Work: To improve current rock slope design to reduce hazard to motorist on NH highways, the following tasks will be undertaken:

Task 1- Smart rock sensor improvements

Improvements being considered include: altimeter data to help locate the rock elevation with time and for matching with video recordings, status test light using a transparent SR shell to ensure the SR is ready for testing between drops and, wi-fi or Bluetooth technology for data download. It is anticipated that several SR will be constructed (5 to 10) to allow cluster rock drops.

Task 2 – Laboratory testing

Experiments will be carried out in the laboratory to calibrate the smart rock sensor, by itself and embedded in a natural rock. The UNH shaking table and the machine shop lathes will be part of the tools used for this purpose. The experiments will also include a series of tests using various rock types equipped with the smart rock to evaluate the restitution coefficient between the rock and other surfaces such as concrete, asphalt, gravel, sand and turf.

Task 3 – Field experiments

Rockfall experiments will be carried out at approximately 10 rock cuts rated A or B according to the New Hampshire Rockfall Hazard Rating System. A tentative list is shown in Table 1. The sites listed in Table 1 will provide a wide spectrum of rock types, slope types as it relates to roughness (i.e. developed by various construction methods; presplit vs production, and natural conditions), slope angles, landing/ditch layout (e.g. gravel, road, grass, etc.).

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Priority Rating	Route	Location	Height (ft)	Rock Formation	General Rock
A	93	AT MILE 97 NORTHBOUND - East side of I93 between MM 96.4 and 96.6 - AKA Barron Mtn Cut	140	Rangeley	Metamorphic
B	89	1.2m South of I89 SB Sutton Rest Area, at MP24.3, SW side, on curve, 2.7m S. of I89 Exit 10	25	Kinsman Granodiorite	Old Igneous
B	89 SB	0.4 MILES SOUTH OF MILE 40	36	Bethlehem Granodiorite	Old Igneous
B	125	WEST SIDE OF ROAD. ON UPHILL.	15	Eliot	Metamorphic
B	120	1m North of I89 Ext.18, CUT ON EAST AND WEST SIDES OF NH120.	35	Biotite Granite	Old Igneous
A	135	EAST SIDE OF NH135, AROUND CURVE, JUST North of MONROE US POST OFFICE, 0.6m South of #335r rock cut	30	Rangeley	Metamorphic
A	10	1/4m S OF GRAFTON COUNTY COMPLEX, W side of NH10, N of mp 119.8, just North of NHDOT North Haverhill shed #204	45	Pink Biotite Granite	Old Igneous
A	112	AT KANCAMAGUS PASS before scenic overlook (on left) cut on both sides of road. LIVERMORE/LINCOLN TOWN LINE	25	Conway	Mesozoic Igneous
A	16	JUST NORTH OF EXIT 13 ON SPAULDING TURNPIKE. BOTH SIDES OF ROAD.	45	Perry Mountain	Metamorphic
B	16	0.1 MILES SOUTH OF EXIT 17. BOTH SIDES OF ROAD.	33	Rangeley	Metamorphic
B	16	EAST SIDE OF ROAD AT MILE NUMBER 25. ACROSS FROM CUT NUMBER 118R.	34	Perry Mountain	Metamorphic
B	16	WEST SIDE OF ROAD. AT MILE MARKER 25.	60	Perry Mountain	Metamorphic
B	103	SOUTH SIDE. 1 MILE EAST OF TRAFFIC CIRCLE	25	Kinsman Granodiorite	Old Igneous
B	101	101/122 INTERSECTION ON-RAMP TO 101 WEST	30	Gneiss	Gneiss
B	31	0.7 MILES N OF OLD WILTON ROAD. 0.2 S OF GREENVILLE/WILTON TOWNLINE	20	Rangeley	Metamorphic
A	12	AT KEENE SURRY TOWNLINE CUT MAKES UP BOTH SIDES OF ROAD, AROUND CORNER	32	Ordovician Dome	Old Igneous
A	103	0.1m West from I89 Exit 9 ON NH103, North side of Road	60	Kinsman Granodiorite	Old Igneous
A	103	1m EAST OF BRADFORD-WARNER T/L, Both sides of NH103, 3.0 m EAST OF NH114/NH103 Jct., 3.7m West of I89 Exit 9	30	Kinsman Granodiorite	Old Igneous
A	3A	0.6m North of NH11 & NH3A Int., Both sides of NH3A - portion of rock formation the West side of Franklin flood control dam	55	Rangeley	Metamorphic
A	93 NB	EXIT 8 NORTHBOUND EXIT/ONRAMP	65	Gneiss	Gneiss
B	11	South of cut 072r, on east bound (west side) of roadway.	35	Winnepesaukee Tonalite	Old Igneous
B	112	ROUTE 112, SOUTHERN SIDE OF ROAD, 0.7 MILES EAST OF KANCAMANGUS PASS AND LINCOLN/LIVERMORE TOWN LINE.	20	Conway	Mesozoic Igneous
B	3	E. side of US3, on a curve, @ MP 139.4, 0.25m NE of Jct. w/ NH 141 & US3 (Const. slope/berm N. end of cut, @ MPs 139.2-139.4)	31	Littleton	Metamorphic

Table 1: NH Rock Cuts A and B Rated

Experiments with the smart rocks will include natural rocks of various sizes and shapes. Experiments using multiple rocks dropped at the same time and at the same location will be conducted to evaluate repeatability, dispersion, and the effect of collision. For each rock cut, a minimum of 3 experiments at the same location and using the same drop technique will be carried out for statistical evaluation of trajectories and runout.

Each experiment with the SR will include video recording of the drop, measurement of lateral dispersion, estimates of rock bounce, measurements of runout, full acceleration and rotation spectra in 3-axes.

Task 4 – Analysis

For the 10 rock cuts selected for testing, a concurrent funded project using the STIC grant program will develop highly detailed 3D point clouds for these rock cuts. The results of the STIC work will serve as input for the smart rock models.

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For each rockfall experiments, the acceleration and rotation data will be analyzed using MATLAB in terms of time domain and frequency domain to assess which approach will yield the most useful information for design. The SR data coupled with the 3D point clouds will be used in software packages such as Rockfall, RAMMS, CRSP and others. The results from the software analyses will be compared to field observations. The reliability of these methods will be tested, and a documented approach will be proposed to improve their prediction capability.

Using the accelerations and rotation rates, the kinetic energy for each drop will be assessed and documented for future possible use in barrier design. All data will undergo a statistical analysis and present maximum, minimum and average values of runout and expected forces.

Task 5 – Recommendations

The work conducted as part of Tasks 1 – 4 will be used to develop the following:

- a) Design evaluation protocol for new and existing rock slopes
- b) Design charts – major revision of Ritchie's model
- c) Develop parameters for rock analysis
- d) Collaborate with other research groups and populate existing databases

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

A total of 85 experimental rockfalls at all proposed rock cuts (9 in NH and 1 in VT) have been completed in late Fall 2020. This summer, three additional rockfall tests were conducted in a high-hazard road cut in Barnet, VT. These tests were performed with collaboration from VTrans and Peters Construction Consultants. This quarter additional field work has included revisiting previous testing locations. The catchment ditches at each site were also measured to revise rockfall protection and behavior design charts currently used based on the experimental data. In addition, lightweight deflectometer (LWD) and dynamic cone penetrometer (DCP) tests were conducted. The visited sites included Warner, Danbury, Orange, Windham, Keene, Franklin (3 slopes), and Franconia, New Hampshire.

Until early summer 2021, preliminary laboratory experiments have been completed as an initial step to develop a small-scale testing program, which we will complete this fall. These preliminary tests have been used in initial model comparisons and especially in adjusting the methods and materials for the upcoming laboratory tests.

Additionally, six updated Smart Rocks were purchased and received. The new 5th generation sensors include additional features such as double the battery life and a hook in the 3D shell to facilitate sensor retrieval after testing. These sensors will be used in our upcoming field and laboratory experiments.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc...):

None.

Anticipated research next three(3) months:

We will use the new sensors to evaluate repeatability, dispersion, and collision effect when multiple rocks are dropped at the same time from the same location. We are also anticipating testing at a scaling project in Merrimack, NH, later this fall.

The catchment ditch measurements, Smart Rock data, runout measurements, and video observations will be used to revise design charts currently used in rockfall protection, including those developed by Ritchie (1963) and Pierson et al. (2001).

After the previously described preliminary laboratory tests, additional experiments will be conducted during the fall semester to better assess rockfall modeling input parameters. Drop tests using the Smart Rocks will be performed using standardized concrete blocks and impact surfaces, including rock, sand, gravel, and asphalt. We have purchased two rocks (with smooth and rough surfaces), and the UNH technical service is currently constructing a frame system to support and adjust these rocks at different testing angles.

Anticipated investigation with the Smart Rock also includes analyses in the time and frequency domains using MATLAB and continuing the data analysis from past field experiments.

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Circumstances affecting project:

Due to the Coronavirus pandemic, UNH facilities were closed after spring break 2020, and the initial field tests planned for the end of March had to be postponed to early June. The laboratory work resumed in late May. With the help of an undergraduate research assistant, Hannah Miller, we were able to accelerate our work during the summer and fall. We have requested and received a no-cost extension so that we can use the upcoming summer and fall to complete our analyses and field testing.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
<i>Task 1: Smart rock sensor improvements</i>	100	100
<i>Task 2: Laboratory testing</i>	100	75
<i>Task 3: Field experiments</i>	100	100
<i>Task 4: Analysis</i>	100	85
<i>Task 5: Recommendations</i>	100	70

Barriers or constraints to implementing research results None.